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ADAPTIVE TEMPERATURE CONTROL IN CONTINUOUS STIRRED TANK REACTOR

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ABSTRACT

This paper presents a PID adaptive controller with a suitable tracking capability for a particular class of plants, namely those exhibiting well damped dynamics and relatively small time delay. Such a controller is used to handle a reactor temperature control problem in a non-isothermal Continuous Stirred Tank Reactor (CSTR).

Keyword: PID; ADAPTIVE CONTROLLER; NON-ISOTHERMAL; CSTR.

1. INTRODUCTION

The chemical process dynamics are very complex and often not completely known. The available models are usually given in terms of nonlinear and non-stationary differential equations derived from mass and energy balance considerations. That is why the underlying control problems are still challenging ones. Remarkable research activity has been devoted to the adaptive control of these processus. A comprehensive overviews of such an effort are given in Astrom (1987) and Morari& Garcia (1988). The motivation of this paper is twofold:

1. A PID adaptive controller incorporating a suitable tracking capability into the design is proposed.
2. A feasibility study involving a physical model of a non-isothermal CSTR is carried out to highlight the considered adaptive control performances.

The paper is organized as follows. The proposed adaptive controller is described in section 2. The experimental evaluation is reported in section 3.

2. THE ADAPTIVE PID CONTROLLER

In this section we describe the main components of the considered PID adaptive controller, namely the underlying PID control plant model, the control objective with the corresponding PID controller and the parameter estimator to be considered.

2.1. The plan model

The input-output behavior of the plan is fairly approximated by the following model:

$$A(\theta, q^{-1})y(t) = B(\theta, q^{-1})u(t-d-1) + v(t) + w(t)$$

$$\Delta(q^{-1})v(t) = \delta(t)$$

With

$$\theta = [a_1 a_2 b_0 b_1]^T$$
$$A(\theta, q^{-1}) = 1 + a_1 q^{-1} + a_2 q^{-2}$$
$$B(\theta, q^{-1}) = b_0 + b_1 q^{-1}$$
$$\Delta(q^{-1}) = 1 - q^{-1}$$

Where u(t) and y(t) denote the input and output, respectively. $q^{-1}$is the backward shift operator. $v(t)$denotes the load distrubances which internal model is given by the polynomial $\Delta(q^{-1})$; $\{\delta(t)\}$ being a uniformly bounded zero mean sequence. w(t) represents the unmodeled plan response.
The PID control design under consideration is well posed if the following assumptions are satisfied:
A1. The plant model exhibits well damped poles
A2. The polynomials $B(\theta, q^{-1})$ and $\Delta(q^{-1})$ are coprime
A3. The sequence $\{|w(t)|[m(t)]^{-1}\}$ is sufficiently small in the mean
Where $m^2(t)$ being an input-output data norm. The assumptions A1 and A2 make it possible to get a state control system. The assumption A3 means that the admissible unmodeled plan response should be linearly bounded, in the mean, by the input-output data norm m(t). This characterizes a relatively important class of plan-model mismatch, including those due to parameter variations and reduced order modeling. Such a class has been first defined in Praly (1982) and subsequently used in recent robust adaptive control investigations.

2.2. The PID controller

We will consider the following PID control law structure

$$S(\theta, q^{-1})\Delta(q^{-1})u(t) + R(\theta, q^{-1})y(t) = T(\theta, q^{-1})\beta(\theta)y^*(t+1)$$

With

$$S(\theta, q^{1}) = 1 + s_1(\theta)q^{-1}$$

$$R(\theta, q^{-1}) = r_0(\theta) + r_1(\theta)q^{-1} + r_2(\theta)q^{-1}$$

$$\beta(\theta) = [B(\theta, 1)]$$

$$T(\theta, q^{-1}) = A(\theta, q^{-1})\Delta(q^{-1})S(\theta, q^{-1}) + q^{-1}B(\theta, q^{-1})R(\theta, q^{-1})$$

The control system resulting from the plan model, without unmodeled dynamics, in closed loop with the above control law is described by

$$T(\theta, q^{-1})\big(y(t) - B(\theta, q^{-1})\beta(\theta)y^*(t)\big) = S(\theta, q^{-1})R(\theta, q^{-1})$$

$$T(\theta, q^{-1})\Delta(q^{-1})\big(u(t) - A(\theta, q^{-1})\beta(\theta)y^*(t+1)\big) = -R(\theta, q^{-1})\delta(t)$$

This control law allows hence to separate the tracking response and the regulation response. The underlying tracking and regulation dynamics are respectively given by

$$y(t) = B(\theta, q^{-1})\beta(\theta)y^*(t) \text{and} T(\theta, q^{-1})y(t) = S(\theta, q^{-1})\delta(t)\$$$

More specifically the $\{e_u(t)\}$ and$\{e_y(t)\}$ sequences represent the input and output tracking errors when the plan model zeros should be preserved in closed loop. This is necessary when the involved plan model exhibit non-minimum phase behaviour which is more a rule than an exception within digital context (Astrom et al (1984)). The input and output tracking errors $e_u(t)$ and $e_y(t)$ can therefore be interpreted as suitable performance quantifiers for systems with arbitrary zeros.

The considered PID control problem has been turned into a regulation problem with respect to the performance quantifiers. Such a regulation problem can be handled using any control design, we will particularly use that which minimizes the following linear quadratic cost function

$$J(t, ph) = E\left\{\sum_{j=1}^{j=ph} \big(e_y(t+j)\big)^2 + \lambda\big(\Delta(q^{-1})e_u(t+j-1)\big)^2\right\}$$

Subject to $\quad \Delta(q^{-1})e_u(t+i) = 0 \quad$ for $\quad i \geq 1$

Where ph is a user integer which could be equal to the rise time in sampling periods and λ is a positive scalar which could be set too small, i.e the floating point zero of the involved computer. This control objective is inspired by the generalized predictive control a pproach proposed in Clarke et al (1987) and the partial state model reference control concept developed in M'Saad (1987).

It can be easily shown that the characteristic polynomial $T(\theta, q^{-1})$ is Hurwitz provided that the prediction horizon ph goes to infinity and the scalar λ goes to zero (M'Sad (1989)). In the practice the prediction horizon is set to the process rise time in sampling periods while the scalar λ is set to a sufficiently small value; i.e the floating point zero of the involved computer.

2.3. The adaptive control law

The adaptive control law is obtained by simply invoking the certainly equivalence principle, which consists in replacing the plant model θ by its estimate $\{\theta(t)\}$, when deriving the PID control law. A remarkable research activity has been devoted to the question of designing parameter estimators that would perform well in realistic situations (See M'Saad (1987) and reference lists therein). In the present feasibility study we will use a robust parameter estimator with and adequate adaptation freezing proposed in M'Saad et al (1989).

3. EXPERIMENTAL RESULTS

The PID adaptive controller proposed above has been used to control the reaction temperature by manipulating the feed flow in a non-isothermal CSTR, which a schematic diagram is depicted in figure 1. The involved plan behavior has been carried out using a realistic physical model derived from mass and energy balances (Aris (1965), Alvarez (1988)).

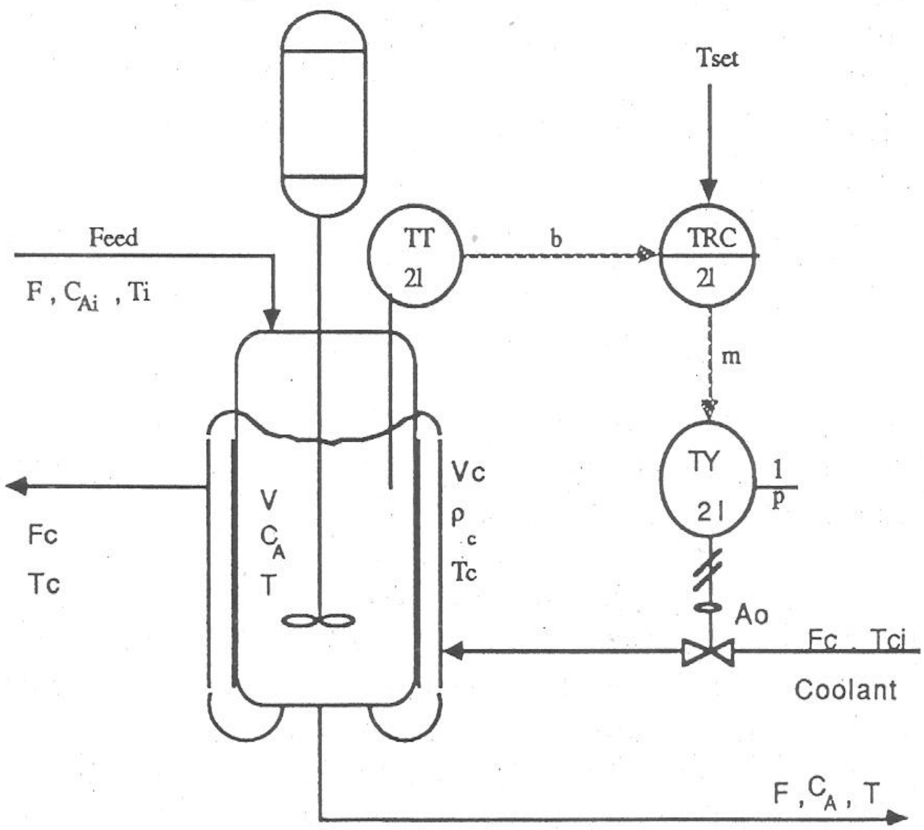


FIGURE 1: Continuous Stirred Tank Reactor

Several experiments involving the above presented plant simulator have been carried out to emphasize the applicability of the proposed adaptive control approach. We will particularly present those concerning the tracking capability, the regulation behavior and the adaptation alertness of the parameter estimator. All these simulation studies have bee carried with the following design parameter choice:

- The sampling period T_s is set to 20 seconds,
- The prediction horizon ph is set to 15,
- The weighting scalar λ is set to 0.0001,
- The reference sequence $\{y^*(t)\}$ is generated by the equation $(1 - .9q^{-1})y^*(t) = 1.u^*(t-1)$ where $\{u^*(t)\}$ is the desired set point sequence.

Figures 2a and 3a show the tracking capability of the proposed adaptive controller in spite of the disturbances' effects. Notice that the specified tracking response is four times faster than the open loop response.

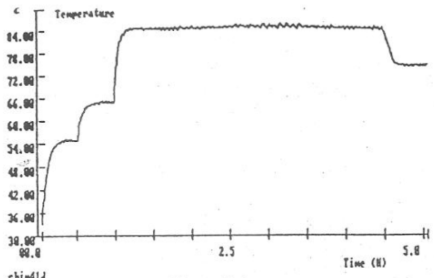


Figure (3a)

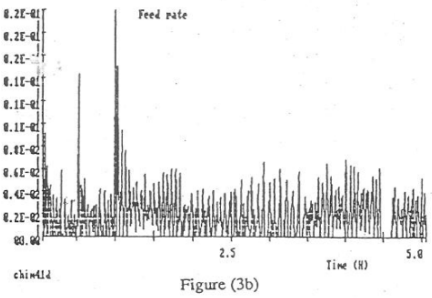


Figure (3b)

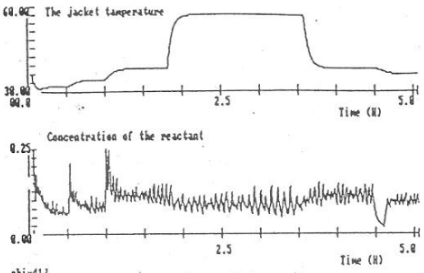


Figure (3c)

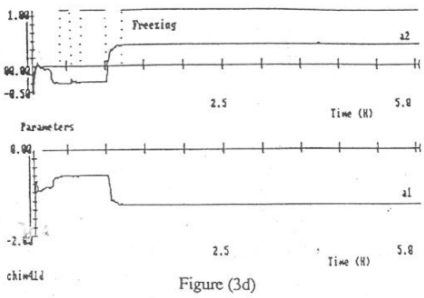
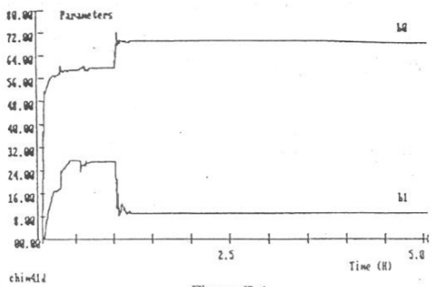


Figure (3d)



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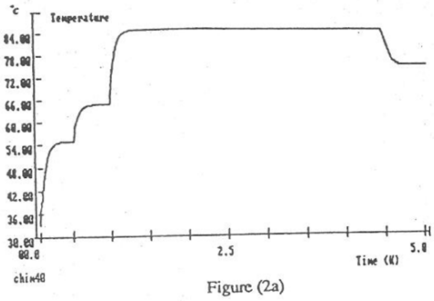

Figure (2a)

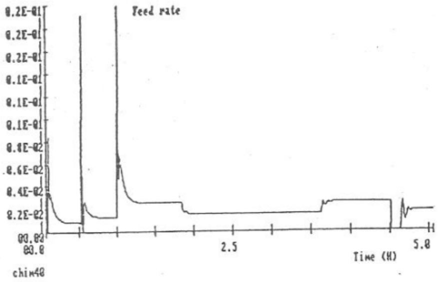

Figure (2b)

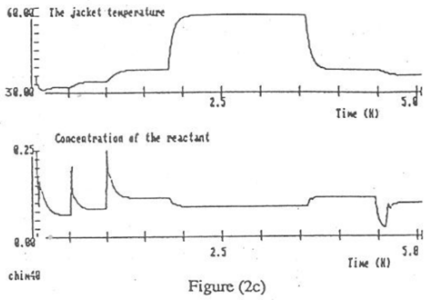

Figure (2c)

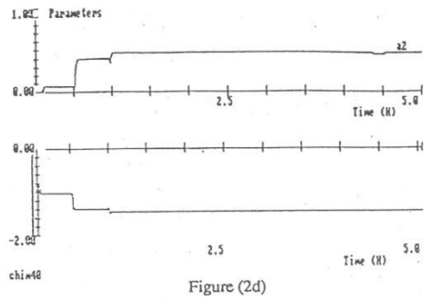

Figure (2d)

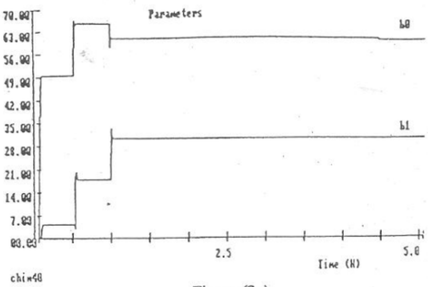

Figure (2c)

Figure 2a, 2b, 2c, 2d ,2e and 3a, 3b, 3c, 3d and 3e: Achieved regulation performance

The regulation capability is illustrated by introducing a step wise disturbance on the jacket temperature and a measurement noise on the reactor temperature. Figures 2a-b-c and 3a-b-c show the

achieved regulation performance which is quite acceptable. The ability of the parameter estimator to deal with time varying dynamics is emphasized in figures 2d-e and 3d-e. Notice that the plan model parameters change when moving from a set point to another and that the parameter adaptation is automatically frozen during the regulation periods.

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